

PROCESS FOR PRODUCING POLYMERIC FILMS  
HAVING SHAPE-MEMORIZING PROPERTIES

BACKGROUND OF THE INVENTION:

5 This invention relates to the production of trans-  
parent films by means of radiation curing. The term  
"shape-memorizing effect" or simply "shape-memorizing  
properties" as used herein means the thermoelastic  
behavior of a material that is plastic at room temperature  
to deform permanently under an external force exceeding  
10 the elastic limit but which is completely restored to the  
initial shape upon heating to a shape recovery temperature  
or above.

Heat-shrinkable films are known as high-molecular  
weight materials that have similar properties to shape-  
15 memorizing resins. However, heat-shrinkable films are not  
completely restored to the initial shape even if they are  
heated and, in addition, they do not have a clear shape  
recovery temperature since they shrink gradually with  
increasing temperature. Because of their thermal elasticity,  
20 shape-memorizing resins are currently used in machine parts,  
medical devices, articles for daily use and toys. Commercial  
shape-memorizing resins are described in Japanese Patent  
Public Disclosure Nos. 53528/1984, 293214/1986, 192440/1987  
and 179955/1988.

25 Resins conventionally known to have the shape-  
memorizing effect include polynorbornane, a styrene-butadiene  
copolymer, polyurethane and polyisoprene. The use of these  
resins has been limited since they can only be given the

initial shape thermal molding or chemical crosslinking. Further, resins shaped by thermal molding are not suitable for use at elevated temperatures and polyisoprene which is shaped by chemical crosslinking has the disadvantage that the shape-recovery temperature cannot be effectively controlled.

#### SUMMARY OF THE INVENTION:

The present invention has been accomplished under these circumstances and has as an object providing a method in which a liquid resin composition that is readily polymerized by irradiation to form a shape-memorizing resin is either applied to a shaped part or placed between films to be given a specified shape and is subsequently cured by radiation to produce a cured film having the memory of the specified shape. The present inventors investigated the mechanical properties of films produced by curing with radiation and found the following two types of formulations that provided films having the shape-memorizing effect:

(1) a resin composition comprising:

- a) an oligomer that has at least one acryloyl or methacryloyl group in the molecule and that has a glass transition temperature,  $T_g$ , of no higher than  $50^{\circ}\text{C}$  after polymerization; and
- b) a low-molecular weight compound that has in its molecule one reactive double bond capable of copolymerization with the oligomer a) and that has a glass transition temperature,  $T_g$ , of at least  $90^{\circ}\text{C}$  after polymerization; or

b') a mixture of two or more low-molecular weight compounds that have in their molecule one reactive double bond capable of copolymerization with the oligomer compound a) and that have a glass transition temperature, T<sub>g</sub>, of at least 90 °C after polymerization; and

(2) a liquid resin composition comprising:

a) an oligomer compound that has at least one acryloyl or methacryloyl group in the molecule and that has a glass transition temperature, T<sub>g</sub>, of no higher than 50 °C after polymerization; and

b) a simple urethane adduct of hydroxyethyl acrylate or hydroxyethyl methacrylate and diisocyanate compound; said liquid resin optionally containing:

c) a low-molecular weight compound that has in its molecule at least one double bond capable of copolymerization with the oligomer compound a).

#### DETAILED DESCRIPTION OF THE INVENTION:

When the resin composition (1) or (2) is cured after being applied to a shaped part, a replica of the shaped part is obtained as the cured film. The cured film is removed from the shaped part and it can be deformed to any shape under an external force. The film remains deformed at room temperature but upon heating to the shape-recovery temperature or above, the film is restored to the initial shape.

The resin compositions can be applied to the shape part by any of the methods used to apply conventional solvent-type resins. Instead of being applied to shaped

parts, the liquid resins may be coated onto or placed between various supports such as plastic films and paper.

The resin compositions may be cured by various methods such as heating in the presence of known radical generators or curing with ultraviolet radiation in the presence of photo-sensitizers. But in view of the objects of the present invention, the most suitable method is curing with an ionizing radiation which does not involve substantial heat generation, particularly with electron beams generated by means of an electron accelerator. The atmosphere for irradiation may be the air but more desirably, it is an inert gas. There is no particular limitation on the energy of electron beams to be applied but an acceleration voltage of ca. 150 - 500 keV is efficient from the view point of production rate.

Examples of the simple urethane adduct b) as a component of the resin composition (2) include a compound having two molecules of hydroxyethyl acrylate reacted to one molecule of isophorone diisocyanate (the compound is hereunder referred to as IA), a compound having two molecules of hydroxyethyl methacrylate reacted to one molecule of isophorone diisocyanate (the compound is hereunder referred to as IMA) and a compound having two molecules of hydroxyethyl acrylate reacted to one molecule of toluene diisocyanate (the compound is hereunder referred to as TA). It is known to combine compound IA with diesters of polycarboxylic acids and use the combinations as adhesive

compositions but such use differs from the use contemplated by the present invention.

The following examples are provided for the purpose of further illustrating the present invention but are in no way to be taken as limiting.

#### Example 1

Urethane acrylate (UX 4101 of Nippon Kayaku Co., Ltd.), IA and cyclohexyl acrylate (CHA) were used as compounds a), b) and c), respectively, in preparing sample of the resin composition (2). UX 4101, CHA and IA were mixed in 40, 40 and 20 parts by weight, respectively. The resulting resin composition was applied onto a tin plate having a conical projection that was 3 cm in diameter and 0.5 cm in height. The composition was cured by irradiating on a conveyor to 50 kGy with electron beams (300 keV) generated from a transformer rectified electron accelerator in a nitrogen atmosphere. The cured film was removed from the tin plate. The projecting cone was collapsed and the film was folded to a smaller size. The film remained in the folded state at room temperature. When the film was dipped into hot water at 60°C, it was restored to the initial shape within 3 seconds. It was also found that the restored shape was identical to the initial shape within a precision of 1%.

#### Example 2

Various formulations of the resin composition (1) were prepared using urethane acrylate (UX 4101 of Nippon Kayaku Co., Ltd.) or urethane acrylate (UV 7700B of the Nippon Synthetic Chemical Industry Co., Ltd.) as oligomer compound

a), and low-molecular weight compounds that were capable of copolymerizing with the oligomer compound a) (for their names, see Table 1).

Each of the compositions prepared from those formulations was placed between two PET films 50  $\mu\text{m}$  thick and cured by irradiating from both sides to 50 kGy (per side) in the same manner mentioned in Example 1, whereupon smooth-surfaced films having thicknesses of ca. 300  $\mu\text{m}$  were obtained.

These films were subjected to measurements of their tensile characteristics using Stograph R1 (Toyo Seiki Seisaku-sho, Ltd.) at a tension speed of 10 mm/min. The films were also subjected to a 180° bending test, in which the films were bent 180° under a pressure of 1 kg/cm<sup>2</sup> at room temperature. Films that broke in the test were rated x and those which did not break were rated o. The permanent deformability of the films at room temperature was evaluated by measuring the angle of the bend in the samples that were left to stand for 24 hours after the 180° bend test. Films with a bend angle greater than 90° were rated o, those having a bend angle of 90° and smaller were rated  $\Delta$ , and those in which the fold disappeared were rated x. The films that had been subjected to the 180° bend test were set in an oven and the temperature was raised stepwisely by 5°C. The temperature at which the fold disappeared was defined as the "shape recovery temperature".

The results of various tests and measurements are shown in Tables 2 and 3.

Table 1 - Monomers Used in Example 2

Monofunctional Monomer:

2-EHA	2-Ethylhexyl acrylate
IOA	Isooctyl acrylate
2-MTA	2-Methoxyethyl acrylate
EA	Ethyl acrylate
MA	Methyl acrylate
CHA	Cyclohexyl acrylate
tBA	t-Butyl acrylate
IBA	Isobornyl acrylate
AA	Acrylic acid
DPA	Dicyclopentanyl acrylate
NVP	N-Vinylpyrrolidone

Polyfunctional Monomer:

HDDA	1,6-Hexanediol diacrylate
NGTD	Neopentylglycolated trimethylolpropane diacrylate
EBAD	Ethoxylated bisphenol A diacrylate
PNGD	Propoxylated neopentyl glycol diacrylate
ETPTA	Ethoxylated trimethylolpropane triacrylate
TMPTA	Trimethylolpropane triacrylate

Table 2 - Resin Formulations Using Urethane Acrylate UX 4101 and the Mechanical Properties of Films Cured with Electron Beams

X	UX 4101/X	Tg of poly X (°C)	Tensile strength (kg/cm <sup>2</sup> )	Elongation (%)	Young's modulus	180° Bend test	Permanent deformation	Shape recovery temperature (°C)
IOA	60/40	-65	20	70	30	o	x	-
2-EHA	60/40	-50	20	90	30	o	x	-
2-MTA	60/40	-50	30	100	30	o	x	-
EA	60/40	-23	40	160	30	o	x	-
MA	60/40	3	200	250	40	o	x	-
CHA	60/40	15	300	240	70	o	x	-
tBA	60/40	41	380	230	300	o	x	-
IBA	60/40	94	410	160	5700	o	Δ	60
AA	60/40	106	680	150	12400	o	o	95
DPA	60/40	120	400	160	4600	o	Δ	50
NVP	60/40	175	560	110	12000	o	o	80
NGTD	70/30	75	320	30	9100	x	x	-
HDDA	70/30		180	30	1500	x	x	-
EBAD	60/40		240	40	5100	x	x	-



Table 3 - Resin Formulations Using Urethane Acrylate UV 7700B and the Mechanical Properties of Films Cured with Electron Beams

X	UV 7700B/X	Tg of poly X (°C)	Tensile strength (kg/cm <sup>2</sup> )	Elongation (%)	Young's modulus	180° Bend test	Permanent deformation	Shape recovery temperature (°C)
2-EHA	60/40	-50	20	40	20	x	x	-
2-MTA	60/40	-50	30	40	20	x	x	-
EA	60/40	-23	60	80	20	o	x	-
MA	60/40	3	130	130	110	o	x	-
tBA	60/40	41	320	110	3800	o	x	-
IBA	60/40	94	300	60	8500	o	Δ	45
DPA	60/40	120	310	50	12400	o	o	45
HDDA	95/ 5		190	60	300	o	x	-
HDDA	90/10		170	40	970	x	x	-
HDDA	75/25		200	20	2800	x	x	-
PNGD	80/20		180	50	320	x	x	-
ETPTA	80/20		220	30	2300	x	x	-

As is clear from Tables 2 and 3, monomer b) has to be a monofunctional low-molecular weight compound having a glass transition temperature, Tg, of at least 90°C after polymerization. If monofunctional monomers having Tg of lower than 90°C are used, the resulting cured films have low Young's moduli and cannot be deformed permanently. If polyfunctional monomers are used, the Young's modulus increases and the cured films become brittle. The tensile strength of cured films is also related closely to Tg after polymerization and it was apparent that satisfactory tensile strength could not be attained when monofunctional monomers of low Tg were used.

### Example 3

Samples of the resin composition (2) were prepared as in Example 2 using urethane acrylate UX 4101 or UV 7700B as compound a), IA, IMA or TA as compound b), and CHA, tBA, IBA or DPA as compound c). The results of various tests and measurements conducted on the samples are shown in Table 4.

Table 4 - Resin Formulations and the Mechanical Properties of Films Cured with Electron Beams

b)	c)	a)/b)/c)	Tensile strength (kg/cm <sup>2</sup> )	Elongation (%)	Young's modulus	180° Bend test	Permanent deformation	Shape recovery temperature (°C)
a) = UV 7700B								
IA	-	95/ 5/0	180	60	760	o	x	-
IA	-	90/10/0	240	60	1700	o	x	-
IA	-	75/25/0	360	50	5100	o	Δ	45
IA	-	50/50/0	490	5	12000	x	x	-
a) = UX 4101								
IA	CHA	40/20/40	310	40	15000	o	o	55
IA	tBA	50/10/40	380	110	9900	o	o	45
IA	IBA	50/10/40	380	60	10000	o	o	65
IA	DPA	50/10/40	380	70	9500	o	o	60
IMA	CHA	40/20/40	360	80	6400	o	o	70
TA	CHA	40/20/40	280	50	6900	o	o	55

As Table 1 shows, the addition of compound b) to urethane acrylate UV 7700B contributed higher Young's modulus and tensile strength but the decrease in elongation was not substantial and the resulting cured films had the desired shape-memorizing effect. The unique effect of compound b) will become apparent by comparison with the UV 7700B/HDDA system shown in Table 3. The addition of HDDA to UV 7700B caused considerable drop in elongation and the cured films became brittle. Many varieties of shape-memorizing films can be produced by adding compound b) and monofunctional monomers to UX 4101.

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